COMPUTATIONAL FLUID DYNAMICS AND EXPERIMENTAL STUDY OF HYDRODYNAMICS IN AN INTERNAL AIRLIFT REACTOR

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Reaktor airlift berasaskan sistem gas-cecair baru-baru ini telah memperolehi perhatian daripada industri-industri tenaga yang boleh diperbaharui dan air kumbahan. Ini turut mendorong penggunaan kaedah komputasi bagi mengatasi had reka bentuk konvensional semasa dan menurunkan kos pengoptimuman. Kebanyakan kajian simulasi gas-cecair menggunakan kaedah dua-cecair model. Walaubagaimanapun, keupayaan ramalan model tersebut bergantung kepada pilihan *closure model* yang tepat untuk mengambil kira daya pertukaran momentum antara gas-cecair yang hilang akibat prosedur *ensemble-average*. Oleh itu, matlamat utama kerja ini adalah untuk membina sebuah computational fluid dynamics (CFD) model bagi reaktor *internal airlift* melalui penjelasan mantap *closure model* dalam dua-cecair model. Kajian ini boleh dibahagikan kepada dua bahagian utama. Pertama, penilaian *closure model* terhadap kuantiti aliran min telah dibuat di dalam reaktor *internal airlift* dengan gas sebahagian terlepas dalam *downcomer*. Simulasi ini menggunakan model turbulensi *k-ε dispersed* melalui model *Eulerian-Eulerian* untuk menyelesaikan medan aliran *transient*. *Closure model* yang dijelaskan dalam kajian ini merangkumi perbandingan model seretan, model daya penyebaran turbulen dan turbulen diinduksi oleh gelembung serta kesan model lif terhadap kuantiti aliran min. Keputusan menunjukkan bahawa hidrodinamik telah diprediksi dengan tepat apabila distorsi gelembung dan gerombolan gelembung diambil kira dalam model seretan melalui model Rayleigh-Taylor. Kuantiti aliran min yang diramalkan oleh *closure model* dengan data experimen segi purata permukaan gas, gas radial dan halaju cecair radial dimana kesilapan masing-masing yang diperolehi adalah 19.4%, 6.8% dan 13.5%. Bahagian kedua kajian ini adalah penilaian *closure model* dalam reaktor *internal airlift* dengan ketiadaan gas dalam *downcomer*. Kaedah model menggunakan dua-cecair model *Eulerian-Eulerian* dengan model turbulensi yang sama. Perbandingan diantara model seretan, kesan model lif dan model daya penyebaran turbulen dilaksanakan untuk predikasi halaju cecair paksi dalam *riser* dan *downcomer*. Predikasi disahkan dengan ukuran laser *Doppler* anemometri (LDA) yang diperolehi dari rig eksperimen. Dalam kajian ini, hasil simulasi menunjukkan ralat margin sebanyak 52.7% melalui model Rayleigh-Taylor, model lif dan model daya penyebaran turbulen. Secara keseluruhannya, keputusan simulasi memperoleh persetujuan yang munasabah dengan data eksperimen dengan ralat margin kurang daripada 20% dari segi gas pengedaran tempatan melalui model seret Rayleigh-Taylor, model lif fungsi nombor Reynolds dan Eötvös serta model daya penyebaran turbulen. Walaubagainmanapun, model dalam kajian ini adalah terhad kepada aliran homogen yang bergelora kerana ketiadaan model matematik yang mengira dinamik gelembung dalam aliran heterogen. Di samping itu, kesan lokasi *sparger* pada medan aliran juga dinilai menggunakan teknik pengukuran LDA. Didapati bahawa posisi X_A = 0.125 m adalah lebih cekap tenaga berbanding sparger pada kedudukan X_B = 0.075 m yang terletak berdekatan dengan dinding baffle. Posisi X_B menghasilkan *recirculation* dan magnitud halaju cecair yang lebih rendah dalam *downcomer*.

ABSTRACT

Gas-liquid airlift reactors have recently garnered interest from renewable energy and wastewater treatment industries, prompting the adoption of flexible computational method to elevate existing conventional scale-up constraints. Most gas-liquid simulation studies employed the two-fluid model owing to its computational affordability. However, the model's predictive capability depends on a proper choice of closure model to account the momentum exchange forces between the gas-liquid interphase lost during the trade-off. Hence, the main aim of this work is to develop a computational fluid dynamics (CFD) modelling approach in the gas-liquid internal airlift reactor via two-fluid model by elucidating the closure model. This study was divided into two main parts. Firstly, an assessment of the closure model on mean flow quantities was carried out in an internal airlift reactor with gas partially disengaged in the downcomer. The simulation employs the dispersed standard k-ε turbulence model through the Eulerian-Eulerian multiphase model to resolve the 3D transient flow field. The closure model elucidated in this work comprised of drag, lift, turbulent dispersion and bubble-induced turbulence forces. Results show that the hydrodynamics was accurately predicted when bubble distortion and bubble swarm were considered in the drag coefficient through the Rayleigh-Taylor model. Mean flow quantities predicted by the closure model were validated against literature data on surface-averaged gas holdup, radial gas holdup and radial liquid velocity of the flow field obtaining mean errors of 19.4%, 6.8% and 13.5%, respectively. Second part of this study extends the assessment of the closure model to an internal airlift reactor with total gas disengagement in the downcomer. The modelling approach employs the Eulerian-Eulerian two-fluid model with the same turbulence model. Comparison studies on different drag, the effect of lift and turbulent dispersion model were carried out to examine the mean axial liquid velocity in the riser and downcomer. Predicted results were validated against laser Doppler anemometry (LDA) measurements obtained from a fabricated experimental rig. It was found that the axial liquid velocity in the riser was severely under-predicted by the spherical drag model. In this study, the simulation results showed a margin error 52.7% when the Rayleigh-Taylor, lift and turbulent dispersion model was employed. Overall, the simulation results obtained reasonable agreement with experimental data with error less than 20% on local gas distribution results through the Rayleigh-Taylor drag model, lift model as a function of Reynolds and Eötvös number and drift velocity turbulent dispersion model. However, the modelling approach in this study is limited to bubbly homogeneous flow due to the absence of mathematical models to account the bubble dynamics in heterogeneous flow. In addition, the effects of sparger location on the flow field was also being evaluated using LDA measurement technique. It was found that the sparger with position X_A = 0.125 m is more energy efficient than sparger with position X_B = 0.075 m as the latter which is located slightly nearer to the baffle wall was producing recirculation flows within the downcomer and lower magnitudes of liquid velocity in the downcomer was observed.

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LIST OF SYMBOLS

τ_l^t	Characteristic time of the turbulence in the liquid
$\tau_{l,g}^t$	Characteristic timescale of the turbulence
C	Coefficient value
A_d	Cross-sectional area in the downcomer
A_r	Cross-sectional area in the riser
v_d	Drift velocity
ε	Energy dissipation
Eö	Eötvös number
K_B	Frictional loss coefficient at the bottom clearance
K_T	Frictional loss coefficient at the top clearance
$\alpha_{g,d}$	Gas holdup in the downcomer
$\alpha_{g,r}$	Gas holdup in the riser
h_d	Gas-liquid dispersion height
$D_{l,g}^t$	Gas-liquid turbulent dispersion term
α_g	Global gas holdup
$\nabla\alpha_g$	Gradient of the dispersed phase volume fraction
g	Gravitational acceleration
$\overline{\mathrm{u}_l \mathrm{u}_g}$	Isotropic turbulence of the velocity correlation tensors
ν	Kinematic viscosity
U_L	Liquid circulation velocity
ρ	Liquid density
v_l	Liquid velocity
μ	Liquid viscosity
d_a	Major dimension of the bubble
D_L	Mass diffusivity
μ_{ref}	Molecular viscosity of water.
Mo	Morton number

β	Piecewise function
σ_{TD}	Prandlt number
d_b	Sauter mean diameter or average spherical bubble size
v_{sg}	Superficial gas velocity
σ	Surface tension between the disperse and continuous phase
u_t	Terminal velocity
$\rho_k \mathrm{u}'_k \mathrm{u}'_k$	Turbulence stresses
k_l	Turbulent kinetic of the continuous phase
μ_c	Viscosity based on Casson model
$k_L a$	Volumetric mass transfer coefficient

LIST OF ABBREVIATIONS

CARPT	Computer Automated Radioactive Particle Tracking
CCD	Charge-coupled Camera
CFD	Computational Fluid Dynamics
LDA	Laser Doppler Anemometry
PDA	Phase Doppler Anemometry
PI	Photographic Imaging
PIV	Particle Imaging Velocimetry

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